VARIATION OF PROCESS PARAMETERS USING THE TAGUCHI METHOD

In the fulfilment of Bachelors of technology degree

Submitted by
V. Sushmitha Choudhary
111ID0484

Department of Industrial Design
National Institute of Technology, Rourkela
Rourkela, Odisha – 769008

CERTIFICATE

This to certify that the thesis entitled "**Variation in process parameters using the taguchi method "** being submitted by **V. Sushmitha Choudhary** for the completion of the final year B.Tech Project in the department of Industrial Design of NIT Rourkela, is a bonafide project work carried out by her under our supervision and guidance. Ms. V.Sushmitha Choudhary has worked for the above problem at the Department of Industrial Design, National Institute of Technology, Rourkela and this has reached the standard fulfilling the requirements and the regulation relating to the degree. I shall take full responsibility for it. I take the entire responsibility for the authenticity of this report and will be responsible if any of the information is illegal or misutilised. The information that has been taken from other sources is purely from study point of view and not to hamper the integrity of the already established research works.

B.B.V.L. Deepak

Assistant Professor,

Industrial Design,

NIT Rourkela

Place: NIT Rourkela

Date: 10th April 2015

ACKNOWLEDGEMENT

I would like to convey my sincere thanks to Prof. Dr. B.B.Biswal, HoD, Dept. of Industrial Design, NIT Rourkela, for providing excellent lab equipment in the Laboratories.

I would like to sincerely thank Prof. B.B.Deepak for teaching me some very important concepts of product design and for his able guidance.

I would like to convey my special regards to Mr. Nagamani Sir for helping me in the rapid prototyping lab without whom this project would be almost incomplete. I would also like to thank all the faculty of our department for their support throughout the project.

I am very much thankful to those, who have been giving inspiration and kind advice without which, it would not have been possible for me to complete this project work.

I thank all our colleagues, friends and well-wishers who have rendered help in this endeavour.

With Sincere regards,

V. Sushmitha Choudhary

111ID0484

ABSTRACT

As of late, RPT has been executed in the industry, especially in the areas of product development. Existing methods give the ability to quickly create a substantial strong part, specifically from three dimensional Computer Aided Design (CAD) information, from a scope of materials, for example, photo curable resin, powders and paper. Much of the time, the final result of a formative cycle is a metallic object with dimensionally steady and of high precision, whether it is a part or a device.

Part testimony introduction is vital variable of layered assembling as it impacts fabricate time, bolster structure, dimensional exactness, surface complete and expense of the model. Various layered assembling procedure particular parameters and imperatives must be considered while choosing the part statement introduction.

Determination of an ideal part affidavit introduction is a troublesome and prolonged errand as one needs to exchange off among different negating destinations like part surface complete and construct time.

It is referred to those process parameters, for example, the air gap between adjoining tracks, raster point, thickness, width of kept layers impact the execution of parts created on a FDM machine.

From the outcomes, it is discovered that FDM parameters, i.e. layer thickness, raster edge and air gap altogether influence the versatile execution of the compliant ABS model. The ideal levels of parameters at diverse edge of removal are likewise introduced.

Nevertheless, the suitable levels of parameters connected with diverse execution criteria still need further examination. A few studies have been directed to focus the ideal parameters of FDM, and execution criteria frequently utilized incorporate form time, quality, sturdiness and surface trustworthiness of the models, typically for infusion trim and tooling applications.

Keywords: Layered manufacturing; Part deposition orientation; Build time; Surface finish; Support structures; raster angle; raster width; layer thickness; air gap.

CONTENTS

LIST OF FIGURES

1. INTRODUCTION

1.1 History

The main type of making layer by layer a three-dimensional article utilizing CAD was rapid prototyping, grown in the 1980's for making models and model parts. This innovation was made to help the acknowledgment of what specialists have as a top priority. Rapid prototyping is one of the prior added additive manufacturing (AM) methodologies. It considers the making of printed parts, not simply models. Among the significant advances that this methodology displayed to item advancement are the time and expense decrease, human collaboration, and hence the item improvement cycle, additionally the likelihood to make any shape that could be exceptionally hard to machine. Be that as it may, at the present time it is not yet embraced in the assembling segment, yet researchers, doctors, students and teachers, economic scientists, and craftsmen use it. With the help of rapid prototyping, researchers and students can quickly fabricate and examine models for hypothetical models and studies. Specialists can fabricate a model of a harmed body to investigate it furthermore, plan better the methodology, economic specialists can see what individuals think about a specific new item, and rapid prototyping makes it less demanding for craftsmen to investigate their inventiveness.

1.2 Rapid Prototyping

Rapid prototyping (RP) is a nonexclusive term for various advances that empower manufacture of physical questions straightforwardly from CAD information sources. As opposed to traditional systems for manufacturing, for example, milling and forging which are of subtractive and formative principles separately, these techniques are taking into account additive principles. The greatest focal point of RP techniques is that a whole 3-D (three-dimensional) consolidated gathering can be created in a single setup with no tooling or human interference, further, the part creation strategy is autonomous of the unpredictability of the part geometry. Because of a few focal points, RP has pulled in the significant consideration of assembling commercial enterprises to meet the client requests for consolidating nonstop and quick changes in assembling in most limited conceivable time and addition edge over contenders. Out of all economically accessible RP courses of action, fused deposition moulding (FDM) uses warmed thermoplastic fibre which are expelled from the tip of spout in an endorsed way in a temperature controlled environment for building the part through a layer by layer deposition technique. Simplicity of operation together with the capacity to create parts with independently controlled properties brought about its far reaching application for prototyping as well as for making practical parts. Nonetheless, FDM procedure has its own negative aspects related with precision, surface completion, quality and so forth. Thus, it is completely important to comprehend the deficiencies of the methodology and distinguish the controllable elements for development of part quality. In this article, present study concentrates on the change of part fabrication technique by appropriately controlling the methodology parameters. The proposition manages different part quality measures, for example, change in dimensional precision, minimization of surface unpleasantness, and change in mechanical properties

measured as far as ductile, compressive, flexural, sway quality and sliding wear. The comprehension created in this work clarify the complex form system as well as present in detail the impact of transforming parameters, for example, layer thickness, introduction, raster edge, raster width and air hole on mulled over reactions with the assistance of measurably approved models, microphotographs and non-conventional streamlining systems.

Rapid prototyping is a collection of systems used to rapidly create a scaled model of a physical part or to assemble utilizing three-dimensional computer aided design information. Rapid Prototyping, also called as 3D printing, is an additive manufacturing technology. Development of the part or assembling is generally done utilizing 3D printing or "additive manufacturing technology" innovation. The main routines for RP have to be accessible in the late 1980s and were used to deliver various models.

The CAD-CAM work process in the customary RP methodology begins with the making of geometric information, either as a 3D solid using a CAD workstation, or 2D slices utilizing an examining gadget. The part is legitimate if for every point in 3D space the computer can focus particularly whether that point lies inside, on, or outside the limit surface of the part. The 3D printing machine peruses the information from the CAD drawing and lays successive layers of fluid, powder, or sheet material — building up the physical model from a progression of cross sections. These layers, which compare to the virtual cross area from the CAD model, are naturally joined together to make the last shape.

CAD post-processors generally approximate the vendors' internal CAD geometric structures with a streamlined scientific structure, which is then communicated in a predetermined information position which is another typical highlight in AM: STL (stereo lithography). Rapid Prototyping utilizes a standard information interface, executed as the STL document organization, to interpret from the CAD programming to the 3D prototyping machine. The STL document approximates the state of a part or gathering utilising triangular aspects.

The pre-processing programming cuts the STL model into various layers from 0.01 mm to 0.7 mm thick, contingent upon the manufacture strategy. The system might generate an auxiliary structure to support the model during the build. Supports are valuable for delicate features, for example, overhangs, interior holes, and slight walled segments.

The last phase of the prototyping is the layer by layer filling of the model material. RP machines construct one layer at once from polymers, paper, or powdered metal. Most machines are genuinely self-governing, requiring minimal human mediation.

Normally, Rapid Prototyping frameworks can create 3D models inside a couple of hours. Yet, this can differ broadly, contingent upon the sort of machine being utilized and the size and number of models being delivered.

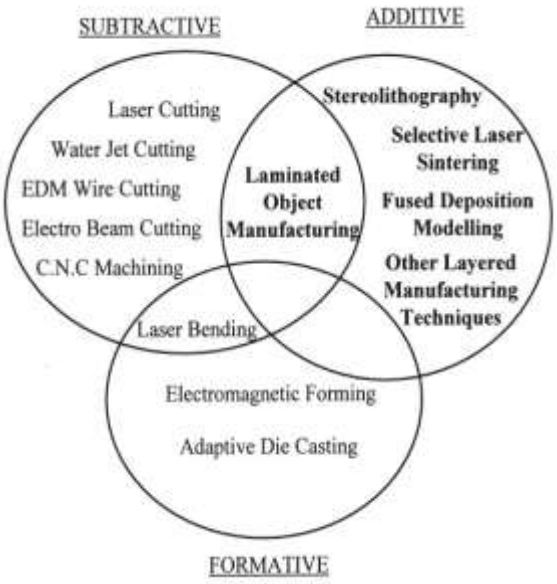

FIG 1: Rapid prototyping techniques [40]

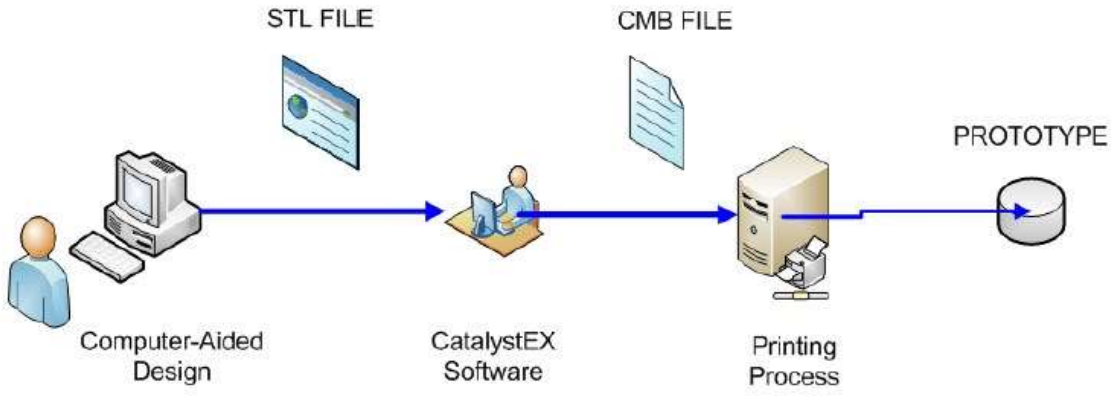

FIG 2: RP Process [40]

2. LITERATURE REVIEW

Two or three trials have been made to update the part precision, parameters by diverse scientists. Pandey and Raghunath [1] have shown that couple of properties are most effective process parameters along X centre point, laser power and shaft speed are fundamental along Y course and bar rate, top partitioning and part develop temperature are critical along Z heading while considering shrinkage phenomena in SLS part. Vasudevarao et al. shown that part presentation and layer thickness have a separating impact on the brutality of parts manufactured utilizing FDM 1650 machine. Further, it has been proposed with respect to the test numerical clarification for discovering the brutality of parts. Es Said et al. [3] have demonstrated that anisotropic direct on mechanical properties is made essentially by virtue of raster presentation when ABSP400 tests are in light of FDM 1650 machine. Khan et al. [4] perceived fundamental parameters and their levels for redesigning the flexibility of FDM part utilizing setup of examinations methodology. Lee et al. [5] performed examinations on tube shaped parts made utilizing three RP outlines FDM, 3D printer and nano composite affirmation (NCDS) to study the impact of gathering heading on compressive quality. Test outcomes display that compressive quality is 11.6% higher for focus FDM test when showed up distinctively in connection to transverse FDM illustration. In 3D printing, inclining case has most noticeable compressive quality in examination to essential cases. For NCDS, critical sample displayed compressive quality 23.6% higher than that of transverse representation. Out of three RP types of progress, parts produced by NCDS are fundamentally influenced by the creation bearing. Anitha et al. [6] utilizes Taguchi structure to focus the impact of layer thickness, raster width and articulation speed each at three levels at first look loathsomeness of part passed on utilizing FDM process. The outcomes exhibit that layer thickness is the most influencing framework parameter affecting surface obnoxiousness took after by street width and assertion speed. Zhou et al. [7] analyzed the impact of five control segments, for occurrence, layer thickness, overcure, gateway partitioning, extremely sharp edge gap, and part domain on assembling stage and couple of picked coordinated efforts on the precision of SLS parts. It has been found that the segment settings for most significant exactness rely on upon geometrical highlights in the part. Campanelli et al. [8] have supported that bring trapdoor over cure and edge overcure must be set at their most significant level for overhauling part accuracy when layer thickness is high. In the event that low layer thickness is fancied then incubate overcure ought to be kept up at medium level and outskirts overcure at most essential level. These methodology settings overhaul part accuracy and also toss the necessity for post curing the SLS part. The already expressed dialogs uncover that properties of RP parts are reliant on particular system related parameters. With genuine change of the accumulate parameters, quality can be by and large enhanced without realizing extra costs in changing made rigging and programming. Further, composed work proposes that studies on impact of method parameters in redesigning nature of FDM made parts, particularly, dimensional exactness, have been centred on a forced degree. Upgrades of machining parameters are develops the utility for machining cash related matters, and fabricates the thing quality, in light of current circumstances, (Azouzi and Guillot,) [9] when the choice variable are sure to just couple of variable and subject to the union of evaluating variability. To make anything with searched for quality by machining, cutting parameters ought to be picked appropriately.

Wardany et al. [10] reported that entering is a psyche boggling operation emerged from other machining operation by virtue of the way that the two reasons of the drill wear obviously until they both have zero slack at the edge, and find the opportunity to be held up inside work piece. The most widely gadget bafflement modes are flank wear, break, pit wear and plastic twisting as reported by Bonifacio and Dinz. [11], Rao [12], Nouari et al[13]. reported essential data about the vital parts impacting the opening quality i.e. cutting rate, temperature, sustenance rate, geometrical parameters and besides the impact of the cutting conditions and the temperature on the gadget life in debilitating. They reported that change of surface quality and dimensional precision of the openings can be accomplished everywhere cutting pace qualities and a feeble sustenance rate. To redesign the EDM advancement, different endeavours have been formed to improve the system security. Bringing outside particles into the working liquid was one of the noteworthy ways to deal with oversee redesign the EDM execution.

3. STEREOLITHOGRAPHY:

Stereo lithography, developed by 3D frameworks Inc. was the first generally utilized technique for quick prototyping thus both are utilized comparatively as a part of the vast majority of the cases. This is a liquid based system that embodies in the curing or establishing of a photosensitive polymer when a splendid laser achieves the resin. The system starts with a model in a CAD programming and after that it is implied a STL record in which the pieces are "cut in slices" containing the information for each layer. Thickness of each of the layers and also the determination depends on the gear used. A stage is assembled to grapple the piece and a support material is provided for supporting the overhanging structures. By then the UV laser is associated with the pitch solidifying specific areas of each layer. Right when the layer is done the stage is cut down in conclusion when the philosophy is completed the extra material is drained and can be reused. A fresher variety of this procedure has been made with a higher determination and is called smaller scale stereo lithography. This process that has a layer thickness of under 10 μm can be accomplished. The vital standard of this technique is the photograph polymerization, which is the strategy where a liquid monomer or a polymer changes over into a set polymer by applying splendid light which goes about as a force for the reactions; this system is moreover called photograph curing. It is moreover possible to have powders suspended in the liquid like pottery

3.1 The STL file:

The STL record was made in 1987 by 3D Systems Inc. at the point when they initially added to the stereo lithography and the STL document remains for this term. It is likewise called Standard Tessellation Language. There are different sorts of records, yet the STL record is the standard for each additive manufacturing procedure. The STL document creation transform principally changes over the persistent geometry in the CAD document into a header, little triangles, or coordinates triplet list of x, y, and z coordinates and the ordinary vector to the triangles. This procedure is mistaken what's more, the smaller the triangles the closer to reality. The inside and outside surfaces are distinguished utilizing the right-hand guideline and vertices can't impart a point to a line. Extra edges are included when the figure is cut. The cutting process likewise acquaints incorrectness with the document since here the calculation replaces the constant form with discrete stair steps. To diminish this error, the strategy for a highlight that has a little span in connection to the measurement of the part is to make STL documents independently and to consolidate them later. The measurement in z direction ought to be intended to have a numerous of the layer thickness esteem.

3.2 SLS:

Selective Laser Sintering is a three-dimensional printing process in which some powder is sintered or fused by the utilization of a carbon dioxide laser shaft. The chamber is warmed to for all intents and purposes the condensing motivation behind the material. The laser merged the powder at a specific territory for each layer controlled by the framework. The particles lie openly in a bed, which is completely controlled by a chamber that is cut down with the same measure of the layer thickness each time a layer is finished. This system offers a remarkable blended bag of materials that could be used: plastics, metals, blend of

metals, mixes of metals and polymers, and blends of metals and ceramics. Tests of the polymers that could be used are acrylic styrene and polyamide (nylon), which exhibit pretty much the same mechanical properties as the implanted parts. It is besides possible to use composites or braced polymers, that is, polyamide with fiberglass. They likewise could be fortified with metals like copper. For metals, a clasp is fundamental. This could be a polymer folio, which will be later cleared by warming or a mix of metals with inside and out diverse softening point. Parts of alumina with high calibre can be created with polyvinyl alcohol, which is a characteristic folio. The principle central purposes of this development are the far reaching mixed bag of materials that can be used. Unused powder can be reused. The downsides are that the precision is confined by the measure of particles of the material, oxidation needs to be evaded by executing the technique in an inert gas air and for the strategy to happen at enduring temperature near to the dissolving point. This method is in like manner called direct metal laser sintering.

3.3 EBM:

A methodology like SLS is electron beam melting (EBM). This procedure is generally new yet is becoming quickly. In this methodology, what softens the powder is an electron laser pillar fuelled by quite a high voltage, normally 30 - 60 KV. The procedure happens in a high vacuum chamber to evade oxidation issues on the grounds that it is proposed for building metal parts. Other than this, the procedure is very much alike to SLS. Electron Beam Melting likewise can transform a high assortment of pre-alloyed metals. Another unbounded advantage of this methodology is the assembling in space, since it is all done in a high vacuum chamber.

3.4 LENS:

In this additive manufacturing process, a part is assembled by dissolving metal powder that is infused into a particular area. It gets to be liquid with the utilization of a high-controlled laser shaft. The material cements when it is chilled off. The procedure happens in a shut chamber with an argon environment. This methodology allows the utilization of a high mixture of metals and blend of them like nickel, stainless steel based amalgams, aluminum-4 titanium-6 vanadium, copper, tooling steel, compounds, et cetera. Alumina can be utilized as well. This procedure is likewise used to repair parts that by different methodologies will be unimaginable or more lavish to do. One issue in this procedure could be the lingering anxieties by uneven warming and cooling methods that can be critical in high exactness methodologies like turbine edges repair.

3.5 LOM:

Laminated Object Manufacturing is a process that joins added substance and subtractive methods to build a part layer by layer. The materials come in a sheet structure in this process. The layers are invigorated together by weight and heat application and using a warm concrete covering. A carbon dioxide laser is used to cut the material to the condition of each layer given the information of the 3D model from CAD and also STL record. The purposes of enthusiasm of this approach are the facilitate, no post curing and supporting structures obliged, no disfigurement or stage change in the midst of the strategy, and the likelihood of building broad parts. The impairments are that the production material is subtracted in this way wasting it, low surface definition, the material is directional ward

for machinability and mechanical properties, and complex internal openings are astoundingly difficult to be made.

3.6 Advantages of rapid prototyping

Rapid Prototyping procedures offer numerous advantages, for example, quick and powerful correspondence of configuration thoughts, viable acceptance of outline fit, shape, and capacity, more noteworthy configuration adaptability, with the capacity to run rapidly through various configuration cycles and less creation configuration flaws and better final items. Different advantages why we utilize quick prototyping is on account of item fashioners might want to have a physical model of another part or item plan instead of simply a computer model or line drawing and a virtual model may not be adequate for the planner to envision the part sufficiently. It helps in making a model is a vital venture in configuration. Utilizing RP to make the model, the fashioner can outwardly look at and physically feel the part and evaluate its merits and weaknesses.

The major advantages are:

- Proof of Concept
- Functional Testing Dimension
- Product Cost Reduction
- Product Confidentiality
- Marketing Tools
- Product Mock ups

3.7 Problem statement

This project studies the various kinds of orientations for simple shapes initially and the time and material both in terms of model and support material consumed for each one of these orientations. Depending on each parameter, we then try to optimize the best orientation according to the complexity of the desired shape. The material optimization in this will be done by varying the orientation and calculating the material in each case. Also parameters like build time are considered in the overall analysis. In this project, we also calculate the variation in length and other physical parameters due to the variations in the process parameters using the Taguchi method.

3.8 Methodology

Initially, the shape of om was taken and the various parameters were varied and readings observed by taking various types of fill types. Then the second case considered was by taking the shape of a cuboid of dimension 15*20*6 mm and the orientations were varied for this by varying the angles along X, Y & Z axis. After all these observations, the further work that will be done in this aspect is to optimize and select the orientation for which the material consumption and build time will be optimum. Then using the Taguchi method, the variations in the physical appearances of the model are noted.

4. 3D PRINTING

4.1 Introduction

3D printing or additive manufacturing refers to any of the different techniques for printing a 3D article. Essentially additive processes are utilized, in which progressive layers are set down under computerised control. The geometry of these items can be varied, and can also be delivered from a 3D model or any other electronic information source. A 3D printer is an example of a modern robot.

There are various applications for AM advances, including construction modeling, development, mechanical outline, car, aviation, military, building, dental and therapeutic commercial ventures, human tissue substitution, style, footwear, adornments, eyewear, training, geographic data, nourishment, and numerous different fields.

A few distinctive 3D printing courses of action have been imagined following the late 1970s. The printers were initially substantial, extravagant, and exceptionally constrained in what they could create. There are different approaches to group the RP procedures that have as of now been created. The RP grouping utilized here are in view of the type of the beginning material: fluid based, strong based and powder-based. The samples of fluid based RP are stereo lithography, strong ground curing and bead statement producing and for strong RP is covered article fabricating and intertwined testimony displaying. Specific laser sintering and three dimensional printing are the powder based RP forms.

A substantial number of added substance courses of action are presently accessible. The principle contrasts between courses of action are standing out layers are saved to make parts and in the materials that are utilized. A few routines dissolve or mellow material to create the layers, e.g. SLM or DMLS), SLS, FDM, while others cure fluid materials utilizing distinctive modern advancements, e.g. SLA. With LOM, meagre layers are sliced to shape and joined together (e.g. paper, polymer, and metal).

4.2 3D Printers

3D printers which are a necessary piece of the quick prototyping process nowadays are an illustration of fused deposition modeling (FDM). Vast 3D printers have been created for techanical, instruction, and definite employments. It is fit for making an article with dimension from 4 feet (1.2 m) to 10 feet (3.0 m) in height. It utilizes plastic pellets as the crude material rather than the regular plastic fibre utilized as a part of other 3D printers. Another kind of vast printer is Big Area Additive Manufacturing (BAAM). The objective is to create printers that can deliver an extensive protest in rapid.

4.2.1 Advantages

- 3D printers are truly simply lower-cost, to some degree less-proficient, quick prototyping or added substance assembling machines.
- They can be utilized as a part of an office domain.
- Accessibility: before, just tech specialists and experts had admittance to this innovation. 3-D desktop printer is open practically anyplace, for example, at home, organizations, clinics and schools.
- Affordable evaluating
- Huge Variety/Customization: Any article can be effortlessly printed paying little mind to whether it is a toy, enlivening thing, or office supply. It doesn't make a difference how complex the outline, 3D printing has opened the way to an unbounded probability of shapes and sizes that can likewise be customized to the client's necessities.
- Improved Life Quality & Welfare
- Constant enhancing prototyping/ expanding profitability: It can help efficiency with a high number of models in less time than customary techniques. Originators can in a flash enhance their models, expanding productivity and the viability of an association. Flawlessness can be attained to in a matter of hours; organizations that utilization this procedure can attain to similar point of interest over their rivals.
- Long item life cycle
- Ease of production and adaptations

4.2.2 Disadvantages

- The major disadvantage is the **slow print speed** of 3D printers which limits their use for mass production.

- Continuous exploration: To diminish this overhead, a few intertwined fibre machines now offer different extruder heads. These can be utilized to print in different hues, with diverse polymers, or to make various prints all the while. This builds their general print velocity amid various occasion creation, while obliging less capital expense than copy machines since they can impart a solitary controller. The print pace expands proportionately to the quantity of heads. Besides, the vitality expense is diminished because of the way that they have the same warmed print volume. Together, these two highlights lessen overhead expenses.
- Violation of copyrights
- Scan & Fraud: 3D printers can be utilized to output and print I.D. what's more, charge cards, auto keys, and additionally a variety of other private paraphernalia.
- Limited Materials: Currently, 3D printers just fabricate items out of plastic, pitch, certain metals, and earthenware production. 3D printing of items in blended materials and innovation, for example, circuit sheets, are still being worked on.
- Size: Currently, 3D printers are restricted with the measure of the items that they can make. At last, expansive things, for example, houses and building, could be made utilizing 3D printers.
- Energy pigs: When dissolving plastic with warmth or lasers, 3D printers devour around 50 to 100 times more electrical vitality than infusion embellishment to make a thing of the same weight.

- Use of non-biodegradable crude material in tremendous sums
- 3D printers make littler parts.
- 3D printers are not as exact: Rapid prototyping machines are more precise and now and again create preferred completes over 3D printers
- FDM is to some degree confined in the variety of shapes that may be manufactured. For instance, FDM ordinarily can't deliver stalactite-like structures, since they would be unsupported amid the fabricated part. Something else, a slim bolster must be outlined into the structure which can be split away

4.3 Materials used

Material used for formation of prototype:

The material utilized as a part of model development is ABS plastic. Acrylonitrile butadiene styrene is a carbon chain copolymer which is made by dissolving butadiene styrene copolymer in a mixture of styrene and acrylonitrile monomers. Acrylonitrile is in charge of giving warmth resistance, butadiene in charge of effect quality and styrene in charge of giving unbending nature. Assembling of example is finished by dissemination welding. This outcomes is non uniform appropriation of material as welding is non consistent. These non-consistency influence the quality of the example and it is consequently important to study effect of diverse methodology parameters on distinctive sorts of quality. Different polymers are utilized, including ABS, polycarbonate (PC), PLA, high thickness polyethylene (HDPE), PC/ABS, polyphenylsulfone (PPSU) and HIPS. All in all, the polymer is as a fiber manufactured from virgin pitches. There are various ventures in the publicly released group went for transforming post-shopper plastic waste into fiber. These include machines used to shred and expel the plastic material into fiber. Thermoplastics like PLA, ABS, HDPE, eutectic metals, palatable materials, Rubber (Sugru), Modeling earth, Plasticine, RTV silicone, Porcelain, Metal mud are likewise utilized regularly as the crude materials. Another sort of material utilized is the polyjets (UV cured tar) and the bolster material utilized for this can be broken down by a high controlled water plane for washing off the jam like bolster material.

Research in crude materials:

3D printing has brought about new materials that have been produced particularly for 3D printers. For instance, fibre materials have been created to mimic wood, in its appearance and also its composition. Besides, new innovations, for example, imbuing carbon fiber into printable plastics, considering a stronger, lighter material. Notwithstanding new basic materials that have been created because of 3D printing, new advances have took into account examples to be connected specifically to 3D printed parts. The material that is used by me in this project is ABS which is a thermoplastic. The support material used is an acrylic support which dissolves in an alkaline rich solution. Its exclusive material properties which make it stand apart from other plastics are:

- Outstanding impact resistance
- Machinability
- Easy to thermoform
- Easy to bond
- Strong and stiff
- Low cost in comparison to its counterparts.

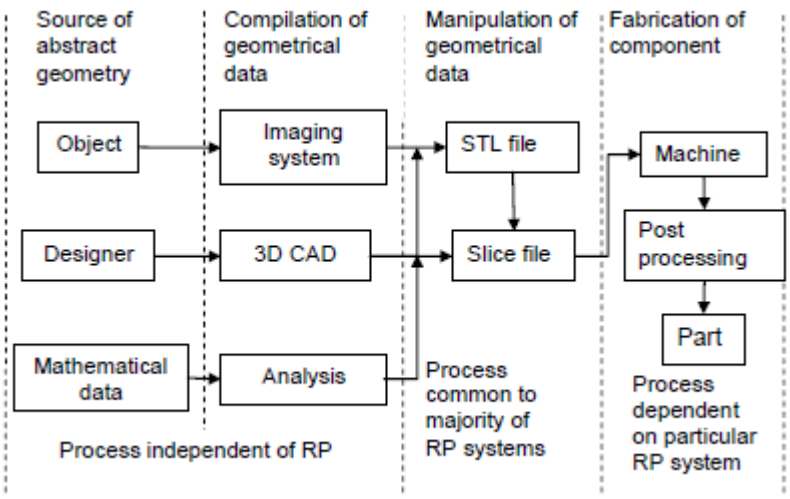

Fig 3: Flow Chart [34]

4.4 Issues in layered manufacturing

1. Deviation from the CAD geometry
2. Part orientation
3. The use of supporting structures.
4. The ‘stair-stepping‘ phenomenon:

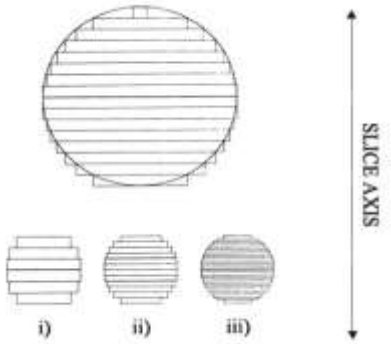

FIG 4: Depicting the stair stepping phenomenon along the slice axis in various orientations (Source: Reference 30)

5. FUSED DEPOSITION MODELING

5.1 Introduction

The concept in FDM is that a filament is given to the machine through a heating element, which is then heated to a molten state. It is fed through a nozzle and then deposited onto the part being built. Since the material is let out in a molten state, it fuses easily with the material around it that has already been deposited. The head is moved in the XY plane and it in turn deposits the material according to the part requirements from the STL file, then the head is moved vertically in the Z plane to begin depositing a new layer. This methodology obliges a support structure to be constructed underneath the areas. In the event that one layer over hangs the one below, it will essentially tumble to the substrate when the FDM spout endeavours to store it. The FDM machine has a second spout that expels bolster material for this reason. The bolster material is like the model material, however it is weaker so that it might be effectively uprooted after the model is finished. The FDM machine fabricates support for any structure that has a shade point of under 45° from level. In the event that the point is under 45°, more than one 50% of one dab is overhanging the cut underneath it, and accordingly is prone to fall.

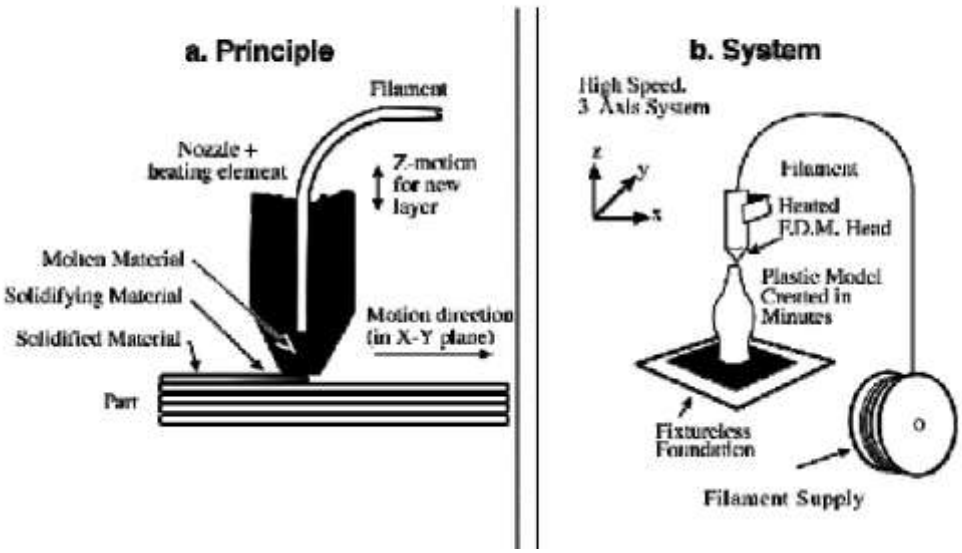

FIG 5: FDM process [41]

5.2 Process parameters

• Raster width: It is the thickness of the dot (or street) that the FDM spout stores which can vary from 0.012 - 0.0396.

• Air Gap: It is defined as the space between the dots of the FDM material. The default value is zero, implying that the dots simply touch. It can be adjusted to leave a positive hole, which implies that the dots of material don't touch. This outcomes in an approximately stuffed structure that constructs quickly. It can likewise be adjusted to leave a negative crevice, importance two dots part of the way involve the same space. This gives

the outcome as a thick structure which obliges a more drawn out form time. A negative air crevice increments both quality and solidness.

• Part Build Temperature: It is the temperature of the warming component for the part material. This controls how liquid the material is when it is expelled from the spout.

• Raster Orientation: The bearings of the dabs of material (streets) with respect to the stacking of the part.

• Colour: FDM ABS material is accessible in white, blue, dark, yellow, green, and red hues.

• Bead width and temperature don't influence quality, yet the accompanying contemplations are imperative. Little dot width builds assemble time and surface quality. Divider thickness of the part ought to be a whole number numerous of the globule width.

• If number of layers is more, it will bring about high temperature angle towards the base of part. This will expand dispersion between nearby rasters and quality will make strides.

• Raster Angle mechanics: It influences the meso-structure and the mechanical qualities of the parts.

• Small raster edges are not best as they will brings about long rasters which will expand the anxiety aggregation along the course of statement bringing about more bending and henceforth feeble holding.

• Thick rasters brings about high temperature close to the boding surfaces which may enhance the dissemination and may bring about solid bond development.

• The execution model of the 3d printer relies on upon the manufacture time, quality, durability and the surface trustworthiness.

• Dimensional Accuracy: It is characterized as the level of understanding between the fabricated measurement and composed determination and it guarantees dimensional repeatability.

• Layer Resolution: Lesser the layer determination, the de-powdering procedure gets to be simpler and quicker. Lesser exertion and time is needed.

• The mechanical quality of the model is influenced by the pore volume and its dispersion.

• Layer thickness: Increasing it diminishes the shear stress, gives great strength and consistency and enhances quality. Diminishing it then again builds the quantity of layers and subsequently higher uprightness and thus expands the quality. Yet, in the event that the quality is diminished more than the immersion level, the cover goes out totally and in this way the material divides out prompting non-consistency in the interface layers.
• Raster orientation: If the introduction is along the z pivot, the model is more inclined to breaks and has lesser quality.

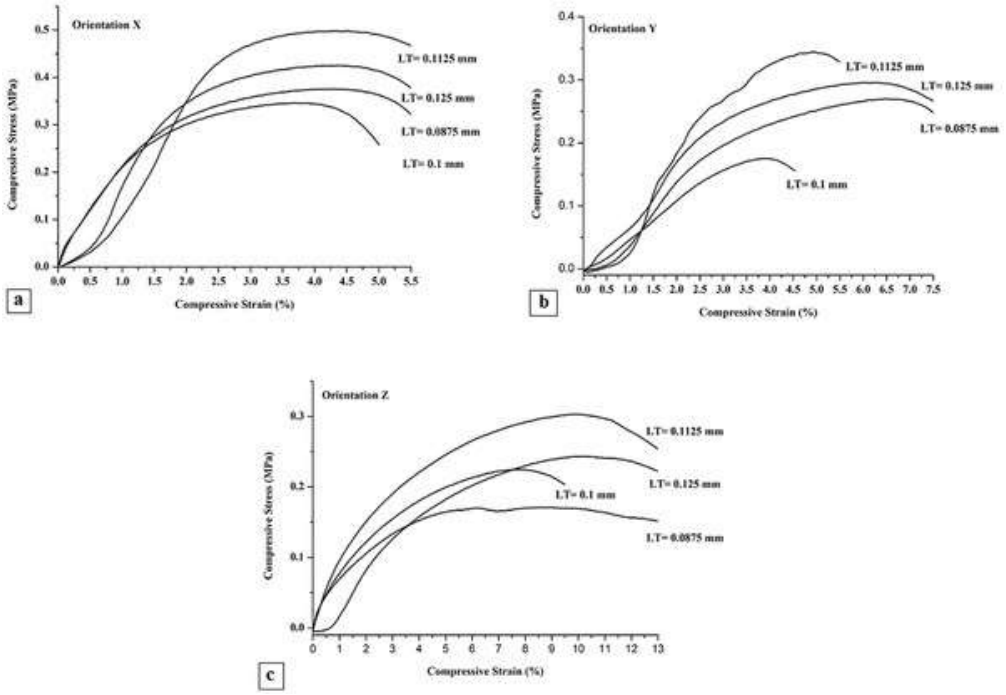

Fig 6: Variation of compressive stress with respect to strain [11-15]

- **Hatching:** In this process the solidifying the cross section of a layer of the whole Part. It affects the sequence and amount of polymer solidification and thus its internal stress distribution and physical properties.
- **Different styles of hatching:** 1) Tri hatch style, 2) weave hatch style, 3) Star weave hatch style, 4) Aces hatch style, and 5) Quick cast hatch style.
- **Hatch Spacing:** Distance between the vectors parallel to each other and is used to hatch the interior. Decreasing it creates a solid layer and increasing it traps the polymer during post curing.
- **Hatch Over cure:** It is the depth to which one cured vector string pierces into the immediate lower layer.
- **Hatch fill cure depth:** It is defined as the depth of the solid layers in the hatching process.

5.3Disadvantages:

Limited accuracy because the shape of material used is 1.27mm in diameter. The main benefit rapid prototyping technologies offers is its ability to manufacture parts of complex geometry without any tooling requirement just by tracing the cad model layer by layer. The ability to manufacture complex parts helps us to substantially reduce production cost, a concept not possible in traditional manufacturing where complexity in design directly resulted in increased cost due to increased cost of machining. One of the other advantages of RP technologies is their ability to produce functional assemblies by consolidating sub-assemblies into one unit thereby reducing the part count, handling time storage requirement. In spite of such added advantages it is not possible to implement on a full scale at industrial level because of its limitations in terms of type of product manufactured. To overcome such limitations new materials have to be developed which can be used in RP technologies. Also the parameter controlling the specimen can be optimized to get maximum utilization of properties of existing products. Since mechanical strength is an important parameter governing the properties of material, therefore in our present study we have made an attempt to study different types of strength like tensile strength, flexural strength, impact strength and compressive strength .After studying behaviour of different types of strength an optimum solution is obtained to get the optimum values of the parameter which govern different types of strength.

5.4 Advantages:

- Quick model generation in least time
- No exposure to toxic chemicals

5.5 Applications:

- Conceptual modelling
- Fits, form applications and models for further manufacturing process
- Investment casting and injection moulding

5.6 TYPES OF SUPPORT FILL:

- **Sparse** fill greatly decreases material consumed, and also the time to print the model. It simply minimizes the amount of support material making models with basic geometry and fastest printing time.
- **Smart** fill: The software calculates the minimum support material required thus improving the build time and minimizing the support material required that reduces the cost. It reduces the build time by 14% and the cost by 40%. As the support descends from underside the part feature to base of supports, the support region is reduced in size thus reducing the material and build time.
- **Surround** fill: In this fill, the complete model is encased in a support material. It is generally used for thin and tall parts since it creates a very stable 3d part. An example where this is used is in the case of a through hole.

Fig 6. Different fills schematically

6. RESULTS

6.1 VARIATION OF MATERIAL AND TIME BY USING DIFFERENT FILL TYPES FOR OM SHAPE:

SUPPORT	**PART INTERIOR**	**TIME** (MINUTES)	**MODEL MATERIAL** (CUBIC INCHES)	**SUPPORT MATERIAL** **(**CUBIC INCHES)
Smart	Solid	20	0.163	0.0242
Basic	Solid	20	0.163	0.0242
Surround	Solid	35	0.179	0.116
Smart	Sparse	19	0.146	0.0242
Basic	Sparse	19	0.146	0.0242
Surround	Sparse	33	0.163	0.116

FIG 7: OM printed using various fill types

6.2 VARIATION OF THE MATERIAL AND TIME FOR A CUBOID BY VARYING THE ORIENTATIONS:

The shape taken in this case is a cuboid of dimension: 15*20*6 mm, the slice height of the layers is kept constant and its value is 0.007 inch.

Table 1: variation of the material and time for a cuboid by varying the orientations:

X(in degrees)	Y(in degrees)	Z(in degrees)	Time(minutes)	Model Material(cubic inch)	Support Material(cubic inch)
0	0	0	10	0.126	0.0109
0	45	0	11	0.113	0.0024
0	0	45	10	0.126	0.0108
0	0	90	10	0.126	0.0109
0	90	0	12	0.118	0.0057
0	45	45	11	0.111	0.0024

0	45	90	11	0.113	0.0024
0	90	45	11	0.115	0.0056
0	90	90	12	0.118	0.0057
45	0	0	12	0.112	0.0021
45	45	0	12	0.11	0.001
45	0	45	11	0.11	0.0021
45	0	90	12	0.112	0.0021
45	90	0	11	0.114	0.0056
45	45	45	12	0.109	0.001
45	45	90	12	0.11	0.001
45	90	45	12	0.118	0.0057
45	90	90	11	0.115	0.0056
90	0	0	13	0.116	0.0046
90	45	0	13	0.11	0.0014
90	0	45	12	0.112	0.0045
90	0	90	13	0.116	0.0046
90	90	0	12	0.118	0.0057
90	45	45	12	0.107	0.0014
90	45	90	13	0.11	0.0014
90	90	45	11	0.114	0.0056
90	90	90	12	0.118	0.0057

Table 2: Variation of process parameters

Factors					
Layer thickness	A	.127	.178	.254	mm
Orientation	B	0	15	30	mm
Raster Angle	C	0	30	60	Degrees
Raster width	D	0.4064	0.4564	0.5064	mm
Air Gap	E	0	0.004	0.008	mm

We can see that for all the orientations we can vary the build time and the material requirement for both model and support material. This variation arises due to the variation of direction of raster, the support material, the delay between the layer to layer printings. The most optimum case in terms of both material consumption and also build time is the case when all the three axis are at an inclination of 45 degrees.

6.3 S/N Ratio:

It is utilized to focus the impact and variety created by every component and association with respect to the aggregate variety saw in the outcome. S/N proportion (g) is given by:

n = -10log10 (MSD)
MSD = t^2 +(Yavg – Y0) ^2 (2)
Where t^2(sigma square) is variance, YAVG is average value of n data points and Yo is target value (Zero in our case).

6.4 Taguchi Method:

Taguchi strategy is best suitable for enhancement of a solitary execution trademark though dim based Taguchi join the whole considered execution trademark (goals) into a solitary esteem that can be utilized as the single trademark as a part of improvement issues. This system approaches for examination and theoretical demonstrating of frameworks for which the data is constrained, inadequate and portrayed by irregular instability. Three execution measures – rate change long, width and thickness are considered with an intent to minimize all these all the while at the single component level setting. To apply this technique, info qualities (execution trademark or target capacity) need to fulfil three conditions for likeness of the diverse arrangement. These are, (1) the contrast between the greatest and least information qualities (assumed control over all traits) is not exactly a request of extent of two, (2) all characteristics are of same sort and (3) all properties have the same estimation scale, and in the event that these are quantitative which have same unit or unit-less. On the off chance that any of these conditions are not met standard standardization is finished.

Table 3: Fixed factors

Fixed Factors		
Style of the Part fill	Perimeter	
Width of the Contour	.4064	Mm
Interior Part style	Solid normal	
Visible surface	Normal raster	
X, Y and Z shrink factors	1.0038	
Perimeter to raster air gap	0.0000	Mm

Table 4: L27 Orthogonal array with S/N ratio Data for Experimental plan:

Experimental plan was carried out based on Taguchi method and results were are shown below Factors and their fixed levels:

Exp No	A	B	C	D	E	%change in L	%change in T	%change in w
1	1	1	1	1	1	24.8066	4.4370	-9.2977
2	1	2	1	2	2	18.4164	7.2636	-11.8583
3	1	3	1	3	3	19.4394	1.5836	-8.2436
4	1	1	2	2	2	26.3151	2.6940	-8.5194
5	1	2	2	3	3	14.3869	6.0206	-11.6715
6	1	3	2	1	1	15.0569	7.2636	-8.5194
7	1	1	3	3	3	30.9540	5.4600	-10.0120
8	1	2	3	1	1	17.2339	3.5218	-12.0412
9	1	3	3	2	2	18.5992	3.9674	-11.4806
10	2	1	1	2	3	38.0618	13.9794	-8.5194
11	2	2	1	3	1	29.5424	2.3079	-12.7364
12	2	3	1	1	2	23.0980	6.0206	-13.0643
13	2	1	2	3	1	20.2945	8.7146	-11.2854
14	2	2	2	1	2	17.0259	7.2636	-13.6849
15	2	3	2	2	3	17.5557	8.7146	-13.0643
16	2	1	3	1	2	22.4028	8.7146	-9.5424
17	2	2	3	2	3	20.7558	3.5218	-12.5678
18	2	3	3	3	1	26.4661	8.7146	-11.2854
19	3	1	1	3	2	22.8937	18.4164	-16.3689
20	3	2	1	1	3	23.9674	7.535	-19.6303
21	3	3	1	2	1	16.5266	12.3958	-19.4779
22	3	1	2	1	3	27.6042	14.8945	-18.7570
23	3	2	2	2	1	28.9143	7.9588	-20.4238
24	3	3	2	3	2	18.2966	10.4576	-16.1462
25	3	1	3	2	3	32.0412	11.0568	-16.3689
26	3	2	3	3	1	24.3172	7.9588	-18.6731
27	3	3	3	1	2	31.7564	7.9588	-17.6921

7. CONCLUSION

The generation of accuracy metal parts and creation tooling direct from CAD drawings has long been the centre of RP industry. In spite of noteworthy advances, RP frameworks always makes parts from materials other than those predefined by part or device originators but it has prompted a few issues, for example, mutilation, dimensional exactness, and poor surface completion.

Nonetheless, high on the toolmakers' list of things to get are hard, wear-safe instruments and mold with complex geometries rendered with a high level of exactness with amazingly great surface quality. Part introduction is one of the essential figures manufacturing a part in layered assembling where the layers assume a significant part regarding part quality, form time and part cost. Three criteria— surface harshness, the manufacture time, and the part cost—are considered when picking the ideal introduction.

Other real traits, for example, dimensional exactness and material property can likewise be considered in future studies for selecting the best RP process. This trial examination has been completed with a perspective of tending to the issue of surface nature of SL item in acrylic based tar which is less expensive and speedier to construct in the stereo lithography process.

The outcomes affirm that streamlining the fabricate parameters will yield great quality item which contrasts positively and those implicit the epoxy based tar. Consequently, the utilization of the ideal form parameters proposed in this study will manufacture parts quicker, less expensive and better.

Further work to be sought after in this field is the improvement of material by fluctuating the FDM parameters particularly the part introduction.

The outcomes anticipated by Taguchi strategy demonstrates that the shrinkage is prevailing along the length and width of the test part though thickness is constantly more than desired quality. The best mix for minimisation of % change in length is higher layer thickness (level 3), orientation(level 1), greatest raster angle(level 3) , medium raster width(level 2), most extreme air gap(level 3). For minimizing the % change in width, it obliges medium raster edge (level 2) and medium air crevice (level 2) and for lower thickness it obliges layer thickness (level 1) ,introduction (level 1) , raster point (level 1), and higher estimation of raster width (level 3) and air hole at level 3. Study on watched results demonstrates that there are expansive number of clashing components autonomously or communication with others may impact the dimensional exactness.

8. SCOPE OF FURTHER WORK

The certification of 3-D printing is in perspective of custom things that are made to demand, for instance, dental and therapeutic contraptions, and low-turnover substitutions parts. These stock are consistently asked for in novel setups and in little sums. A discriminating purpose of enthusiasm of 3D printing is an organization capacity to rapidly and cost effectively supply low demand parts without the peril of passing on an unsold finished items stock. Since things are made exactly when asked for and paid for, originators have the ability to endeavour perils they would not for the most part look for after. With 3-D printing, the peril of a poor setup is considering wasted layout time rather than stock theory. A critical point of convergence of this is the division of thing framework from collecting capacities. Since arrangement and gathering can be smoothly outsourced in 3-D printing, originators can contract with firms, for instance, Shapeways to make, ship, and assemble proceeds for stock in light of their blueprints. Various issues relating to cost, time and accuracy, and nature of 3-D things need to be eliminated before the advancement can finish wide apportionment. A valid example, to the extent cost, materials suitable for 3-D printing can run 10 - 100 times more than common imbuement moulding thermoplastics. Material choices, tones, and surface fulfilments suitable for 3-D printing are moreover more compelled than with typical vast scale producing systems. High material costs in a matter of seconds confine the use of 3-D printing to applications that are high regard, and/or when rate or security is separating. These days, 3D printing works with ABS, pitches, and metals, with a very high level of precision of approximately $1/10^{th}$ of a millimetre. According to sources, the robot arm of a 3-D printer has to be 10 times more correct before it can fight with mechanical planning procedures. There are moreover some quality issues relating to fragile holding between the layers that can provoke breakage under uneasiness; besides, the materials' quality, thickness, and dimensional robustness, impenetrability to warmth, and shading quality need watchful appraisal. Quality issues are very essential when parts made with 3D printing are weight bearing. As the expenses of rough materials drop and material quality enhances, the usage of 3-D development will develop past its accessible degree. Applications that can construct fuse augmentation amassing, to dispatch arranges before thing commercialization and to deal with emergency demands; custom gathering for enhancements and relaxation action applications; parts for equipment and flying machine, where quality is a critical issue; emergency shipments of parts; and circumstances where stock passing on costs are high concerning creation costs. A helper surety of 3-D printing lies in division of thing arrangement from thing creating. As 3-D printing creates, purchasers will have the ability to purchase arranges online and a while later amass things at home. Device associations can similarly contract out the collecting of additional parts to untouchables, which will then frame parts in perspective of CAD programming gave by the machine maker. Parts costs could decrease since no inventories must be kept. Additional part openness can in a similar manner reach out, as it is less excessive to hold old arrangements than plenitude inventories of additional parts. Inside the accompanying 5 years or some place in the region, one can sensibly evaluate different discriminating 3-D printing store system headways on the arrangement side, and additionally the era side. A sweeping number of firms will soon offer CAD-CAM anticipates downloading by last clients, and moreover retailers. These diagrams will enable last clients to convey revamp things at home and grant firms to make new parts when asked for reason. The wide gathering and use of

internet will extend the individuals' ability to investigate the CAD-CAM available frameworks library and think seriously about these to be successfully downloaded. The high number of their applications, the availability of higher-quality materials, and lower material costs will similarly realize a greater number of home and master quality 3-D printers. One can suspect that various noncompeting specialists and firms may moreover choose to together purchase 3-D printers to reduce their endeavour costs, and also the threat of mechanical obsolete nature. In the whole deal, the extent of advanced 3-D printing applications will take off as new 3-D printers have the ability to suit greater things and finish more significant levels of precision. There should furthermore be tremendous declines in material and contraption costs as more individuals and firms grasp this 3-D printing: The new cutting edge change advancement. In addition, the utilization of 3-D printing will develop due to the openness of materials with more noticeable quality and impenetrability to warmth and moistness. Exactly when the expense of 3-D printers is reduced, perhaps to $300 or something like that, the amount of machines used for home applications will unquestionably stretch out from current levels. At this quality level, the business passage of home-based 3-D printers will begin to take after that of minimal laser printers. In like manner with the mechanical business area, extended business passageway will realize additional 3-D home applications. Material costs will similarly decrease as a delayed consequence of higher business invasion. The future holds phenomenal insurance for 3-D printing as a development and for end customers.

9. REFERENCES

[1] Pandey, P.M., Ragunath, N. (2007), "Improving accuracy through shrinkage modelling by using Taguchi method in selective laser sintering", International J Mach Tools Manufacturing, Vol. 47, No.6 , pp. 985-995.

[2] Bharath, V, Dharma, P. N., Anshuman R., Henderson M. (2000), "Sensitivity of RP surface finish to process parameter variation in Solid free form fabrication proceedings", The University of Texas, Austin, pp. 252-258.

[3] Es Said Os, Foyos J, Noorani R, Mandelson M, Marloth R, Pregger BA. (2000) , " Effect of layer orientation on mechanical properties of rapid prototyped samples.", Mater Manufacturing Process , Vol. 15, No.1,pp. 107–122.

[4] Khan ZA, Lee BH, Abdullah J. (2005), "Optimization of rapid prototyping parameters for production of flexible ABS object", J Mater Process Technologies, Vol. 169, pp. 54–61.

[5] Lee CS, Kim SG, Kim HJ, Ahn SH. (2007), "Measurement of anisotropic compressive strength of rapid prototyping parts." J Mater Process Technologies, pp. 630– 637.

[6] Anitha R, Arunachalam S, Radhakrishnan P. (2001)," Critical parameters influencing the quality of prototypes in fused deposition modelling.", J Mater Process Technologies, Vol. 118, pp. 385-388.

[7] Zhou Jack G, Herscovici Daniel, Chen Calvin C. (2000), "Parametric process optimization to improve the accuracy of rapid prototyped stereolithography parts", International J Mach Tools Manufacturing, Vol. 40, pp. 363–379.

[8] Campanelli SL, Cardano G, Giannoccaro R, Ludovic AD, Bohez ELJ. (2007), "Statistical analysis of stereolithographic process to improve the accuracy", Computer Aided Design, Vol. 39, No1. pp. 80-86

[9] Azouzi R., Guillot M. (1998), "On-line optimization of the turning using an inverse process neuro-controller", Transactions of ASME, Journal of Manufacturing Science and Engineering, Vol. 120, pp. 101–107.

[10] El-Wardany T.I., Gao D., Elbestawi M.A. (1996), "Tool condition monitoring in drilling using vibration signature analysis", International Journal of Machine Tools and Manufacture, Vol. 36(6), pp. 687–711.

[11] Bonifac io M. E. R., Din z A. E. (1994), "Correlating tool wear, tool life , surface roughness and tool vibration in finish turning with coated carbide tools Wear" ,Vol. 173, pp. 137-144.

[12] Rao S. B. (1986), "Tool wear monitoring through the dynamics of stable turning", Journal of Engineering for Industry, Vol. 108, pp. 184-189.

[13] Nouari M., List G., Girot F. and Coupard D. (2003),"Experimental analysis and optimization of tool wear in dry machining of aluminium alloy Wear", Vol. 255, pp. 1359–1368.

[14] Alsaran, Celik A, Celik C. (2002), "Determination of the optimum conditions for ion nitriding of AISI 5140 steel." ,Surface Coating Technologies, Vol. 160, pp. 219–26.

[15] Yang LJ. (2001), "Plasma surface hardening of ASSAB 760 steel specimens with Taguchi optimisation of the processing parameters", J Mater Process Technologies, Vol. 113, pp. 521–527.

[16] Wiedemann B, Jantzen HA. (1999), “Strategies and applications for rapid product and process development in Daimler-Benz AG”, Computer Industry, Vol. 39, No.1, pp. 11–16.
[17] Noorani Rafiq. (2005), “Rapid prototyping – principles and application”, New Jersey, John Wiley & Sons Inc
[18] Upcraft Steve, Fletcher Richard. (2003), “The rapid prototyping technologies”, Rapid Prototyping, Vol. 23, No.4, pp. 318–330.
[19] Lotfi Zadeh. (1993), “Fuzzy logic.”Computer 21/4 (1988), 83-93, E. Cox: “The fuzzy system handbook. Academic Press, 510p.
[20] Hopkinson N, Hagur RJM, Dickens PH. (2006), “Rapid manufacturing: an industrial revolution for the digital age”, England: John Wiley & Sons Inc.
[21] Stratasys. FDM Vantage user guide version 1.1. 2004. <www.stratasys.com>.
[22] Venkata Reddy N, Pandey PM, Dhande SG. (2007), “Part deposition orientation studies in layered manufacturing.” J Mater Process Technologies, Vol. 185, pp. 125–131.
[23] Byun Hong-Seok, Lee Kwan H (2006). , “Determination of the optimal build direction for different rapid prototyping processes using multi-criterion decision making”, Robot Computer Integrated Manufacturing, Vol. 22, pp. 69–80.
[24] Ross PJ. (1996), “Taguchi techniques for quality engineering”, USA: McGraw- Hill
[25] Yu JP, Chang CC. (1997). “Characteristic analysis of the EDM surface of tungsten carbideusing Taguchi method”, International conference on precision engineering, Taipei; .pp. 657–663.
[26] Marafona J, Wykes C. (2000), “A new method of optimizing material removal rate using EDM with copper-tungsten electrodes”, International J Machine Tools Manufacturing, Vol.40, pp. 153–164.
[27] Vijaya M, Krishna R, Prabhakar O, Shankar NG. (1996), “Simultaneous optimisation of flame spraying process parameters for high quality molybdenum coatings using Taguchi methods.”, Surface Coating Technologies, Vol. 79, pp. 276–288.
[28] Fallbohmer P, Altan T, Tonshoff HK, Nakagawa T. (1996), “Survey of die and mold manufacturing industry”, J Mater Process Technologies, Vol. 59, pp. 158–168.
[29] Peace Glen Stuart. (1993), “Taguchi methods a hand on approach”, New York: Addison Wesley publishing company
[30] Liao YS, Chiu YY. (2001), “A new slicing procedure for rapid prototyping systems.” International J Adv Manufacturing Technologies, Vol.18, pp. 579–585.
[31] Pandey Pulak Mohan, Venkata Reddy N, Dhande Sanjay G. (2003), “Slicing procedures in layered manufacturing a review.”, Rapid Prototyping J , Vol. 9(5), pp. 274–288.

[32] Shen Y.K., Chien H.W., Lin Y. (2004) ,"Optimization of the micro-injection molding process using Grey relational analysis and Mold Flow analysis", Journal of Reinforce Plastic Composite, Vol. 23, pp.1799–1814. [36] Lin C.L. (2004), "Use of the Taguchi method and Grey relational analysis to optimize tu rning operations with multiple performance characteristics", Journal of Material Manufacturing Process, Vol. 19 (2), pp. 209–220

[33] Yih-fong Tzeng, Fu-chen Chen. (2007), "Multi-objective optimisation of high-speed electrical discharge machining process using a Taguchi fuzzy-based approach", Journal of material design, Vol. 28(7), pp. (1159-1168)

[34] Sood, A.K., Ohdar, R.K. and Mahapatra, S.S., (2009), "Improving dimensional accuracy of Fused Deposition Modelling processed part using grey Taguchi method" ,Journal of material and design , Vol. 30(9) ,pp. (4243-4252)

[35] Mahapatra, S.S., Nanda, S.K., Prasanna, K. and Garg, S. (2010), "Prediction of Erosion Wear Rate of Cement By-pass Dust Filled Hybrid Composites using Fuzzy Logic", Journal of material and design, Vol. 30(8), pp. 2791-2801.

[36] Antony J. (2001), "Simultaneously optimisation of multiple quality characteristics in manufacturing process using Taguchi's quality loss function", International J Advanced Manufactured Technologies, Vol. 17, pp. 134–138.

[37] Introduction to fuzzy logic using MATLAB by Sivanandam S.N, Sumathi S. and Deepa S.N

[38] Sood A.K,Ohdar R.K , and Mahapatra S.S ,(2009)"Improving dimensional acuuracy of processed part using grey taguchi method",Journal of materials and design.Vol30(9),pp(4243-4252).

[39] Anitha R,Arunachalam S,Radhakrishnan P,(2001)"Critical parameters influencing the quality of prototypes in fused deposition modelling",Journal of material science technologies,Vol 118pp(385-388).

[40] www.wikipedia.com

[41] www.google.com